Journal of Forestry Research (2012) 23(3): 461-466
DOI 10.1007/s11676-012-0285-x

ORIGINAL PAPER

Patterns of tree buttressing at Lawachara National Park, Bangladesh

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Received: 2011-07-24; Accepted: 2011-11-07

Abstract: We describe patterns of buttress formation and development in eleven tree species at Lawachara National Park, Bangladesh. Forty-five percent of trees of these 11 species had buttresses. *Artocarpus chaplasha* Roxb. showed maximum (87%) buttress formation, whereas *Alstonia scholaris* (L.) R. Br. did not show any buttress. Buttresses were recorded in 20%-40% of trees of six species and 40%-60% of trees in three species. Mean length and height of buttress varied among the species and ranged from 0.37-1.37 m and 0.71-2.13 m, respectively. Buttress height, mean buttress length, total buttress length, and total length plus length of secondaries increased with DBH (diameter at breast height) and tree height. Buttress number did not increase with DBH or tree height. Under-storey and mid-canopy trees produced less developed buttresses than did emergent trees ($p<0.01$). Wood density showed moderate effects on buttress characters ($p<0.05$), while the slope of the land did not. Canopy category was a primary regulating factor for tree buttressing, suggesting that buttresses are mechanical adaptations of trees to counter physical stresses.

Keywords: buttresses; tree architecture; canopy category; slope of the ground; wood density

Introduction

Buttresses are large roots formed by tall or shallowly rooted trees, and they can prevent the tree from falling and aid in acquiring nutrients (Young and Perkocha 1994; Crook et al. 1997; Newbery et al. 2008). Temperate forest trees typically have fewer buttresses than tropical trees and buttresses are a distinctive feature of tropical rain forests (Richards 1996). It is generally held that buttresses mainly play a mechanical role to provide stability and prevent the tree from falling. The structural hypothesis was explained on mechanical engineering principles by Mattheck (1991), who showed how secondary sinker roots below the buttresses can anchor the whole structure by spreading and absorbing the stress optimally over a large surface area, counteracting the compression forces. Higher stress in a tree is found at the junction of stem and horizontal roots, and a tree can reduce the risk of being snapped at this junction by producing buttresses on both sides of the trunk (Mattheck and Kubler 1995).

Buttresses form on one side of the tree are more completely developed on one side, which can usually be determined to be the windward side or the side opposite to the lean (Richter 1984; Crook et al. 1997; Ter Steege et al. 1997). Generally, the largest buttresses occur on one side opposite to the largest part of the crown (Young and Perkocha 1994). The effect of wind on buttress position was confirmed by earlier studies (Richter 1984; Ennos 1993; Warren et al. l988; Chapman et al. 1998). However, Richter (1984) argued that crown asymmetry can change quickly over time due to loss of branches and changing access to sunlight, while buttresses are a more permanent feature on a tree once they are formed. Thus the relation between crown asymmetry and buttressing cannot be too strong. Previous studies also showed that buttresses begin to develop in forest trees long before the crowns of those trees reach canopy level where they are exposed to full wind (Richards 1952; Kaufman 1988). A buttressed tree can probably attain more rapid growth into the canopy and exploit a more flexible growth strategy than can un-buttressed tree. This is because, as the tree crown grows laterally into gaps in the canopy, the increasing asymmetry in load is better supported. Richter (1984) showed, however, that there is no relationship between crown asymmetry and buttress induction. Chapman et al. (1998) concluded that buttress formation appears to be correlated with full crown development in dominant trees.

Bangladesh is a tropical country, where buttressing is common in natural and plantation forests. It is important to explore forest characteristics here to understand their structures and functions. Our objective was to explore the patterns of tree buttressing and their relationships with tree architectural parameters (DBH and tree height) at Lawachara National Park, Bangladesh. We also analyzed the effects of canopy category (under-storey, mid-canopy and emergent), wood density, and land slope on buttress

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Responsible editor: Yu Lei

characteristics.

Materials and methods

Study area

The study was conducted at Lawachara National Park, which was once under west Bhanugach Reserve Forest under Sylhet Forest Division of Bangladesh and is situated 60 km south of Sylhet city in the Komalgonj Upajila of Moulvibazar District. The forest is managed by the forest department as a protected area covering 1,250 ha with the remaining 281 ha under West Bhanugach Reserved Forest. The forest is semi-evergreen (Feeroz and Islam 2000), and lies between 24° 30'-24° 32' N and 91° 37'-91° 39' E. The study area has a monsoonal climate with one dry and one wet season. Average annual rainfall in the study area is about 4,000 mm, and the temperature varies on average from a minimum of 26.8° C in February to a maximum of 36.1° C in June (NSP 2006).

Sampling and field measurements

We collected data from 10 randomly selected plots (50 m × 20 m). Plots were established only in the natural portion of the forest. To demarcate plot boundaries, two meter tapes were used and the plot boundary was defined by four poles in four corners. Plot locations were recorded using a GPS (Magellan® Triton™ 2001) from the approximate middle point of the plot. We measured numbers of buttresses, lengths of all buttresses, and lengths of secondary projections coming off from the main buttresses, heights of all buttresses, tree heights, and DBH for eleven species (DBH > 10 cm). Each tree was categorized as emergent, mid-canopy and under-storey according to tree height (Chapman et al. 1998).

Tree height (m) was measured by Sunntu Clinometer (Suunto PM5-360) and DBH (cm) of each tree was measured by a diameter tape above the buttresses. Buttress numbers were counted for each tree. Buttress length (m) was measured by meter tape from the bole of the tree to the uppermost surface of the buttress where it first entered the ground. Buttress height (m) was measured by meter tape from the ground to the point where the buttress became even with the trunk of the tree. Wood samples were collected by an increment woodborer (Haglöf Sweden®), and the slope of the ground was measured by Sunntu Clinometer.

Measurement of wood density

Wood samples were collected from outer into the inner portion of the trunk of standing trees. Each tree (DBH > 10 cm) was sampled from the selected plot area. A wood core was extracted from each sample tree at a point above the buttress from the periphery to the inner portion of the trunk with increment borer. Samples were placed immediately in an airtight container to prevent drying out for measurements of green volume. Wood volume was determined by assuming that the core is cylindrical, with $\pi r^2 h$, where r is the radius (2.1 mm) and h is the length of the core sample, which was measured with a digital caliper (Chave et al. 2006). Basic density was measured using the oven-dry method (Chowdhury et al. 2009).

Statistical Analysis

Data was analyzed by SPSS Software (SPSS, ver. 17, Chicago, IL, USA). Relationships between tree diameter and height versus buttress characteristics (e.g., buttress number, height and length) were determined by liner and non-linear regression analysis, respectively. The effects of canopy category, land slope, and wood density on buttress characteristics were reflected by multiple regression analysis. In multiple regression analysis, the canopy category was used as a dummy variable (e.g., 0, 1 & 2). Comparisons among the canopy categories (under-storey, mid-canopy and emergent) were done by analysis of variance (ANOVA) followed by post-hoc (Games-Howell) test.

Results

Overall statistical descriptions of buttress characters for each species are listed in Table 1. 238 trees (DBH > 10 cm) of 12 species were measured in 10 plots, and 45.4% of trees had buttress. Of 12 species only one (*Alstonia scholaris*) did not show any buttress. Therefore, the buttress formation was analyzed in 11 species. Six species developed buttresses in 20-40% of trees. Three species developed buttresses in 40-60% of trees. *Artocapus chaplasha* showed maximum buttressing at 87% of trees (Fig. 1). Buttress formation was also analyzed in three canopy categories. The percentage of buttress trees in three canopy categories varied. Under-storey trees had 33.7% buttressing (n = 35), mid-canopy trees had 47.3% buttressing (n = 44), and emergent trees showed maximum buttressing of 70.7% (n = 29).

Except for total buttress number, all linear regressions of buttress characteristics with tree diameter were highly significant (p<0.01) (Fig. 2). Non-linear regression (exponential) showed tree height and buttress characteristics to be significantly related (Fig. 3).

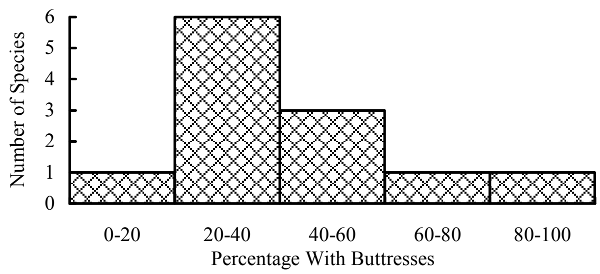

Fig. 1 Numbers of species in five classes of buttressing percentage based on 238 trees of 12 species at Lawachara National Park.

The effect of canopy category, land slope, and wood density on buttress characteristics were explored using multiple regressions analysis. All measures describing buttress size were strong-

ly related with DBH (p<0.01) so we used the residuals from the regression analysis to control for tree size. Canopy category had a significant effect on buttress characteristics except for the number of buttresses (Table 2). Wood density had a moderate inverse relationship with buttressing, while land slope did not show any effect. Except for buttress number, all buttress characteristics differed significantly between the three canopy categories. The post-hoc tests showed that buttress characteristics (except buttress number) of the under-storey and the mid-canopy trees were significantly different from those of the emergent trees.

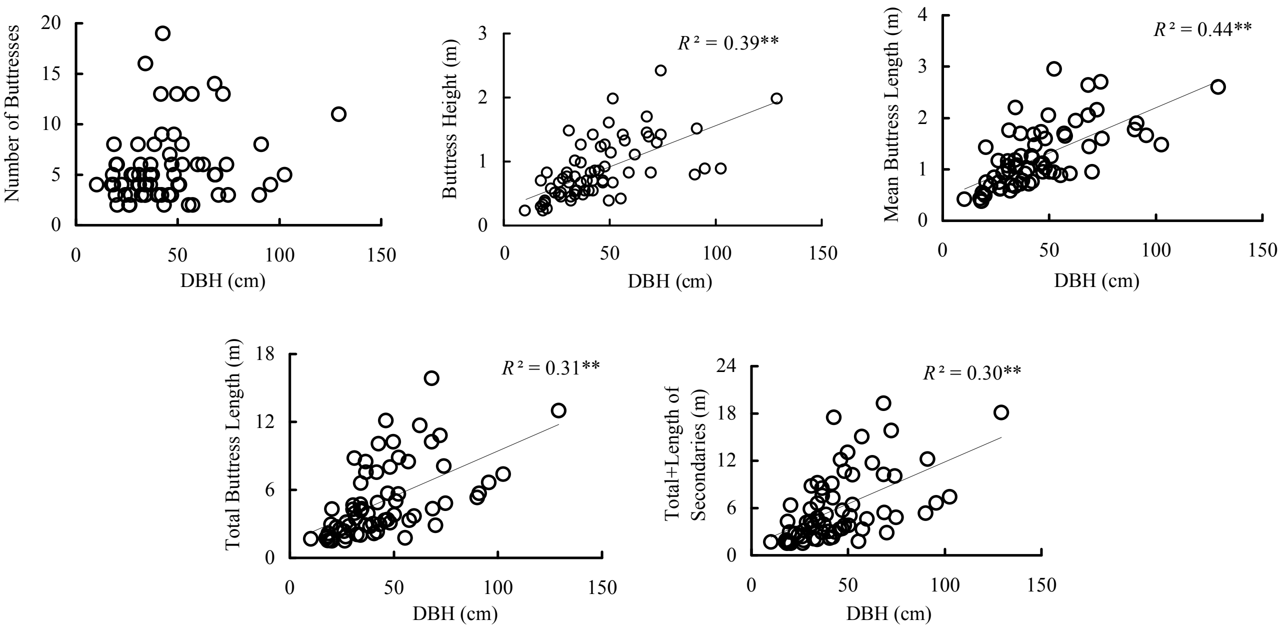

Fig. 2 Relationship between DBH and buttresses number and size (buttress height, mean buttress length, total buttress length and total plus length of secondaries). **: p < 0.01; ns: not significant; n = 67.

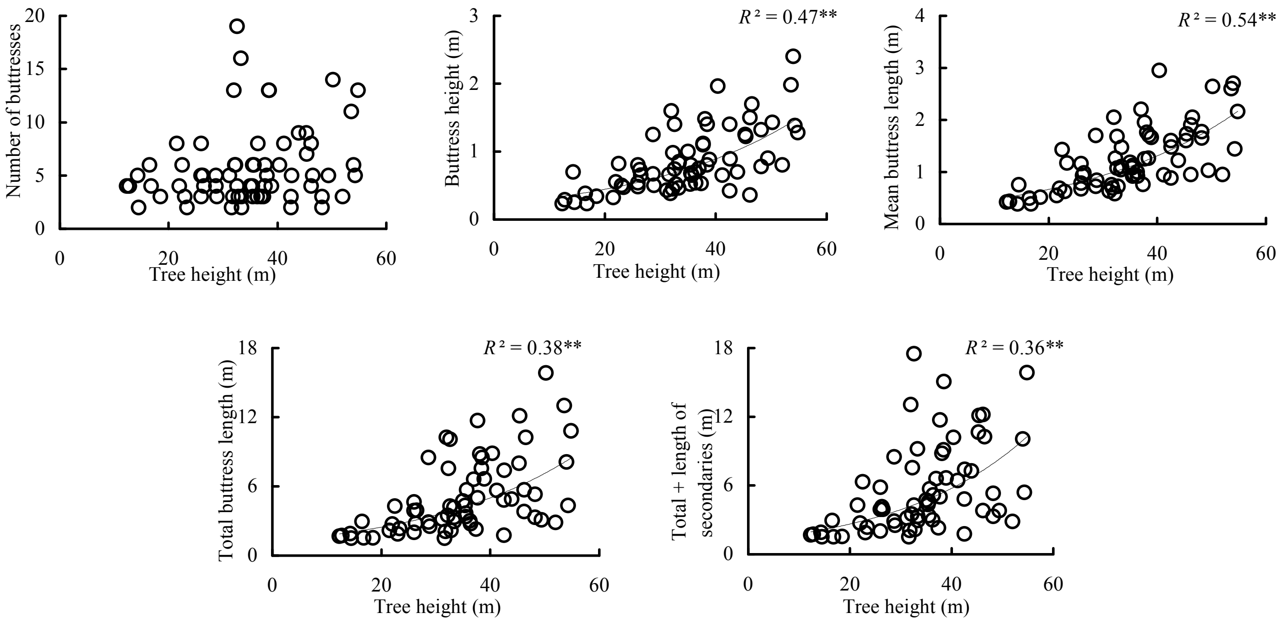

Fig. 3 Relationship between tree height vs. buttresses number and size (buttress height, mean buttress length, total buttress length and total plus length of secondaries). **: p < 0.01; ns: not significant; n = 67.

Table 1. Description of the tree architecture (DBH, tree height) with buttress characteristics of 12 species found at Lawachara National Park

Scientific Name	Family	N T/ NTB	DBH (cm) Mean ± SD	TH (m) Mean ± SD	BN Mean ± SD	BH (m) Mean ± SD	MBL (m) Mean ± SD	TBL (m) Mean ± SD	T+2ndL (m) Mean ± SD	WD (g· m-3) Mean ± SD
Alstonia scholaris (L.) R. Br.	Apocynaceae	8/0	24.78±10.17	23.38±7.85	-	-	-	-	-	0.35±0.04
Artocarpus chaplasha Roxb.	Moraceae	31/27	54.73±22.93	40.63±9.32	5.37±3.26	1.01±0.50	1.42±0.64	5.45±3.74	6.55±4.98	0.45±0.07
Artocarpus lacucha Buch-Ham.	Moraceae	28/10	33.10±11.86	30.01±10.18	3.50±1.18	0.47±0.15	0.81±0.19	2.79±1.04	2.79±1.04	0.45±0.04
Chickrassia tabularis A. Juss.	Meliaceae	18/8	56.73±28.10	39.18±11.78	5.13±3.00	1.09±0.47	1.41±0.50	5.20±3.13	6.20±4.52	0.63±0.02
Crataeva nurvala Buch-Ham.	Capparidaceae	22/9	50.78±34.96	31.14±11.55	4.22±1.20	0.63±0.26	1.01±0.53	4.28±2.47	4.28±2.47	0.52±0.15
Elaeacarpus robustus Roxb.	Elaeocarpaceae	18/7	31.76±16.20	28.66±12.91	9.57±5.68	0.71±0.44	0.96±0.57	5.39±4.19	7.59±5.78	0.53±0.07
Ficus hispida L. f.	Moraceae	26/14	37.79±11.63	31.96±7.92	7.00±3.66	1.05±0.47	1.45±0.61	6.09±2.82	7.48±3.95	0.30±0.06
Holigarna longifolia Buch-Ham.	Anacardiaceae	28/10	33.27±11.76	30.66±9.81	4.20±1.14	0.82±0.41	1.04±0.47	3.81±1.94	4.26±2.38	0.38±0.05
Salmalia insignis (Wall.) Schott & Endl.	Bombacaceae	14/9	55.78±28.03	39.46±11.35	7.67±3.46	1.37±0.73	2.13±1.43	9.56±6.83	13.49±11.08	0.46±0.04
Schleichera oleosa (Lour.) Oken.	Sapindaceae	17/5	42.32±13.18	37.62±7.50	4.20±0.84	0.73±0.30	1.10±0.37	4.75±2.37	4.75±2.37	0.61±0.07
Syzigium fruticosum Roxb.	Myrtaceae	14/5	42.10±14.75	31.446.84	5.40±1.14	0.80±0.13	1.30±0.10	4.19±0.61	5.50±1.36	0.60±0.05
Terminalia belerica Roxb.	Combretaceae	14/4	33.28±3.31	28.18±5.60	3.50±1.73	0.47±0.11	0.71±0.22	2.78±2.34	2.78±2.34	0.63±0.02

NT is the number of trees found on the plot and NTB is the number of trees with buttresses. DBH is the diameter at breast height, and TH is the tree height. BN is the number of buttresses, BH is the buttress height, MBL is the mean buttress length, TBL is the total buttress length, T+2ndL is the total buttress length plus length of secondaries, and WD is the wood density of trees with buttress. All buttress characteristics are measured in the unit of m.

Table 2. Coefficients of multiple regressions between buttress characteristics versus other factors (canopy category, slope of the ground and wood density).

Dependent variable	Independent variable			
	Canopy category	Slope (°)	Wood density (g· cm-3)	R^2
Number of buttresses	0.25ns	-0.11ns	-0.02ns	0.05ns
Buttress height (m)	0.50**	-0.14ns	0.25*	0.37**
Mean buttress length (m)	0.44**	-0.13ns	0.30*	0.35**
Total buttress length (m)	0.58**	-0.09ns	0.12ns	0.36**
Total plus length of secondaries (m)	0.58**	-0.06ns	0.13ns	0.39**

ns: non significant; *: p<0.05; **: p<0.01.
Canopy category was used as dummy variable in the analysis

Discussion

The percentage of buttress formation in the study area varied with tree size (DBH): larger trees had a greater proportion with buttresses did smaller trees (10-30 cm DBH = 33%, n = 36; 30-60 cm DBH = 67%, n = 50 and > 60 cm DBH = 86%, n = 22). Chapman et al. (1998) also showed that about 69% of trees with DBH > 70 cm had buttresses in Kibale National Park, Uganda. Of all trees in our study, 45% trees had buttresses, indicating that buttress formation in our study area is more frequent. In our study area, the frequency of buttress formation varied between species and even within a single family (Table 1). About 87% of trees formed buttresses in *A. chaplasha*, 35% in *A. lacucha*, and 53.8% in *Ficus hispida*. This difference can also be seen within a single genus, as reported by Chapman et al. (1998). Of 12 species in our study, only *A. scholaris* did not form buttresses. This could be due to interspecific difference of tree architectural patterns. *A. scholaris* is medium sized tree (medium diameter,

height, straight bole, small crown size and whorled branching) that reaches only to mid-canopy level. Moreover, site-specific differences cannot be excluded. Baker (1965) documented a similar example of variable buttress formation in *Ceiba pentandra*: in a forest environment, it is always buttressed but in the savanna, it is unbuttressed.

The relationship between DBH and buttress characteristics exhibited that the buttress height and length increase linearly with DBH but buttress number did not (Fig. 2). Woodcock et al. (2000) found similar results in *Elaeocarpus angustifolius*. However, Newbery et al. (2008) found no relationship between DBH and number of buttresses in *Microberlinia bisulcata*. Buttress characteristics except buttress number in our study were significantly related with tree height (Fig. 2). Richter (1984) reported that buttress height rapidly increased with tree height in *Quararibea asterolepis*. So, it is clear that buttress characteristics (buttress height, mean buttress length, total buttress length, and total plus length of secondaries) depend on tree architectural parameters (DBH and tree height). Buttress number might have some others functions, such as water and nutrient acquisition in the upper soil surface (Newbery et al. 2008). The canopy category showed a significant relationship with buttress characteristics (except buttress number), and these characteristics were more developed in emergent trees than in mid-canopy and under-storey trees, probably to counter asymmetric loads. This suggests that when a tree grows from the under-storey to mid-canopy and emergent levels, the pattern of buttressing also changes to maintain overall mechanical stability. Similarly, Chapman et al. (1998) compared three categories (under-storey, canopy level and emergent) in two different sites (logged and unlogged) and noted that canopy category has a significant effect on buttress number and size. Slope has no effect on buttress characteristics in our study area. Similarly, Wahala et al. (2005) reported that slope of the ground has not significant effect on buttressing.

We also predicted that wood density might influence the buttress characteristics, because weak stems might have a higher risk of falling and therefore require better developed structural support. It is well known that wood density is strongly correlated with strength properties, i.e., modulus of elasticity (Kollman and Côté 1984). However, our results showed that it had moderate effect on buttress height and mean buttress length. The ability of a stem to resist compression or bending (i.e., flexural stiffness) is the product of the modulus of elasticity and the second moment of area (Niklas 1992), where the second moment of area of a circular cross-section is defined as $\pi D4/64$ and is a structural property that is determined by the stem diameter (D). Trees might increase stem diameter instead of wood density, yielding greater momentum area (Gartner et al. 2004). Trees of larger diameter have larger buttresses for additional support to increase stem resistance against physical stresses.

Conclusion

Buttress formation varied by species at Lawachara National Park. Mean buttress height and length varied between tree species from 0.47-1.37 m and 0.71-21.3 m, respectively. For 11 tree species, buttress characteristics except for numbers of buttresses (buttress height, mean buttress length, total buttress length, and total plus length of secondaries) were strongly related with tree architectural parameters (e.g., DBH and tree height). Wood density showed moderate relationship ($p<0.05$) with buttress height and mean buttress length. Land slope did not show any relationship with buttress characteristics. Canopy category (under-story, mid-canopy and emergent) was strongly related to buttress characteristics in our study area ($p<0.01$), and the under-storey and mid-canopy trees had less developed buttresses to counter physical stresses.

Acknowledgments

We thank Bangladesh Forest Department for their permission and assistance with the field works.

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